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INT CL[6] G01D 5/26 5/32 5/34 5/347 5/36
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(54) **Displacement sensor having a grating with an antisymmetric periodic pattern**

(57) A displacement sensor has a grating with an antisymmetic periodic pattern (1) of reflective material, wherein each period (2) has three strips (5,6,7) of material of different reflectivity arranged in sequence. Part of the grating is illuminated by a beam (8) of light and movement of the grating reflects the light to produce a code signal. The code signal is decoded by decoding means to determine the direction and extent of displacement of the grating. The sensor may also have a pseudo-random binary sequence pattern running alongside the antisymmetric periodic pattern, an LED light source, optical fibres transmitting source and reflected light between the controller unit and grating, and a GRIN lens to focus light onto the grating.

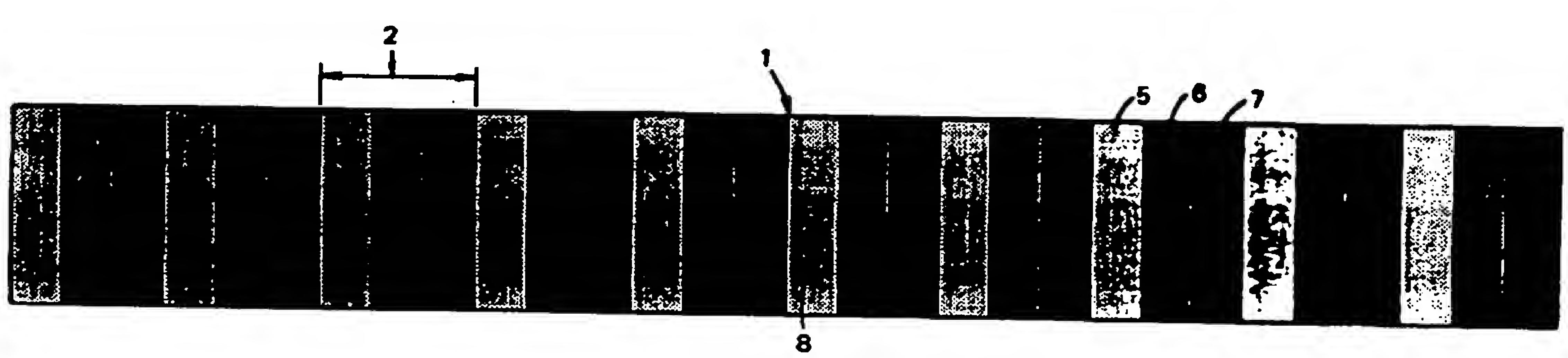

FIG. 1

GB 2 297 840 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

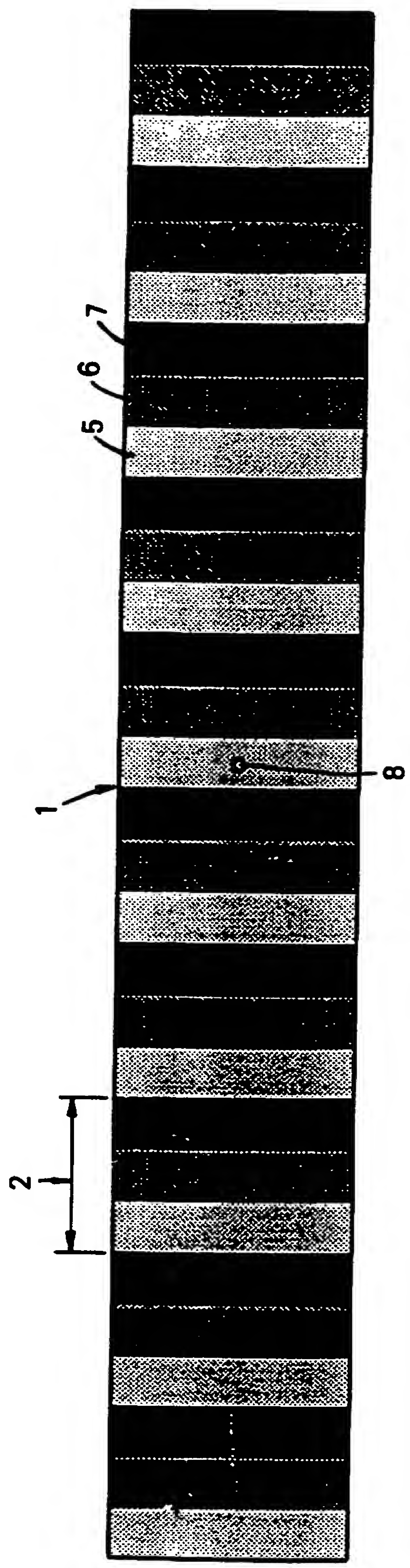

FIG. 1

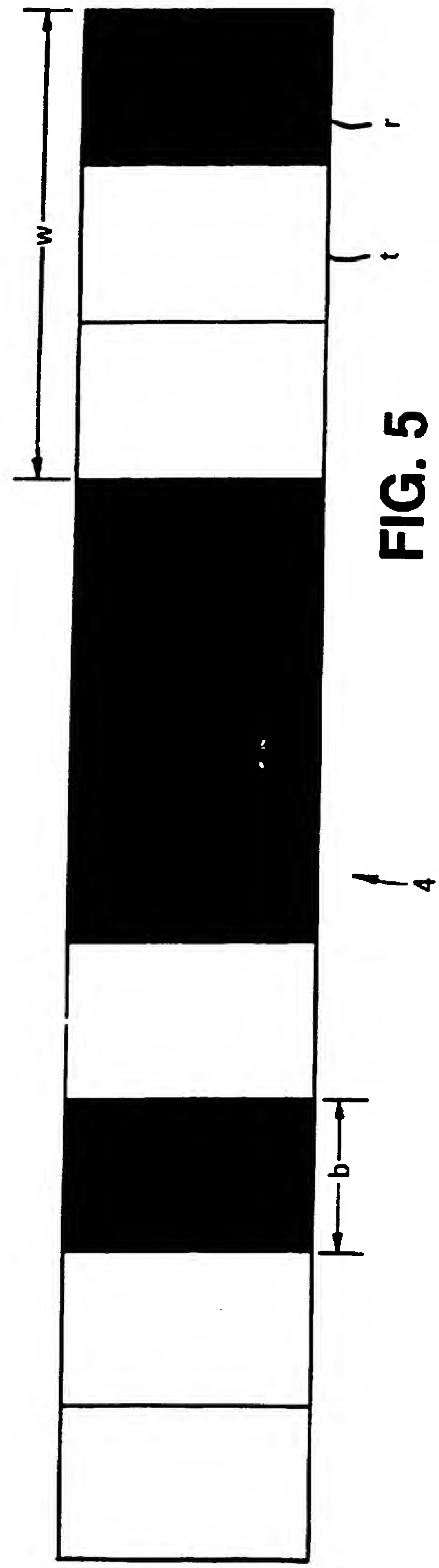

FIG. 5

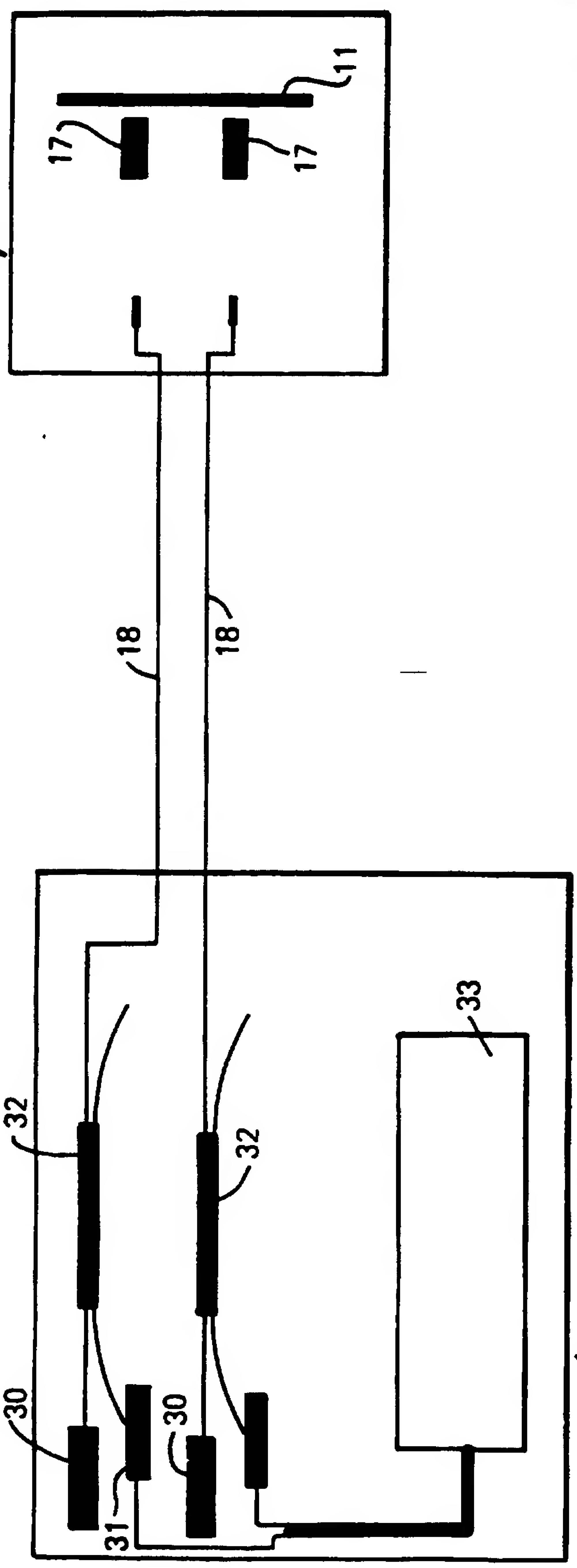

FIG. 2

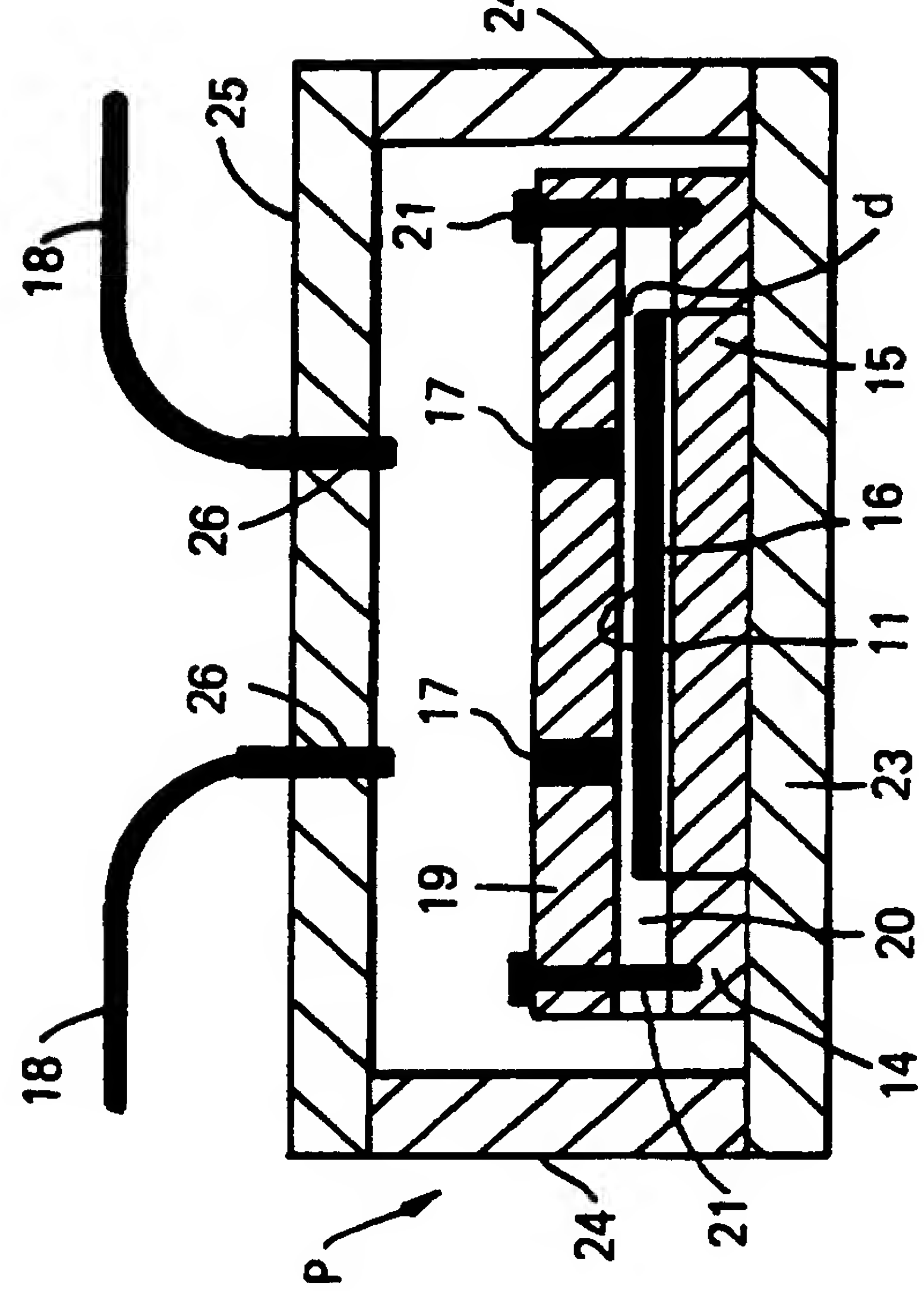

FIG. 4

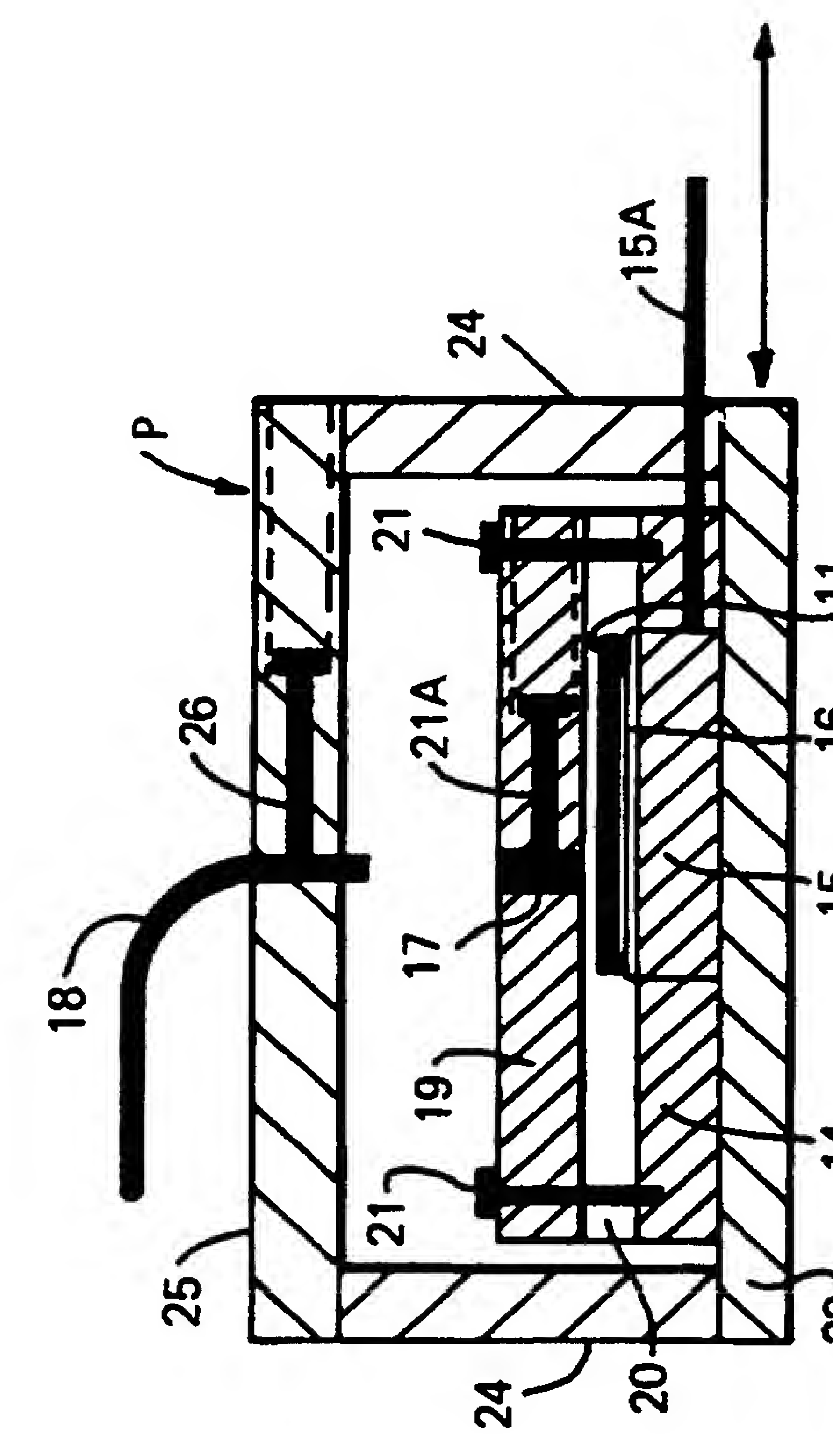

FIG. 3

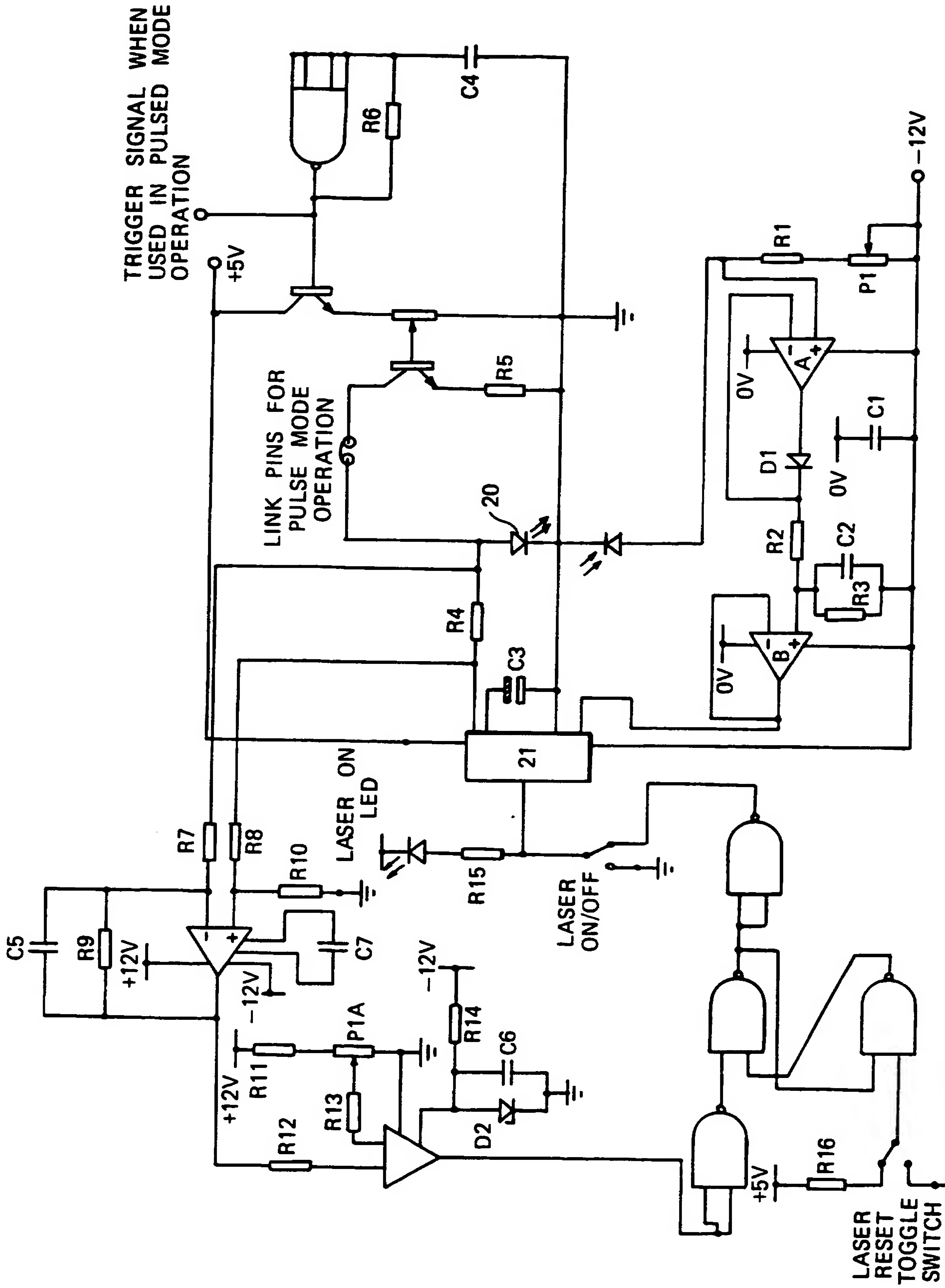
TRIGGER SIGNAL WHEN USED IN PULSED MODE OPERATION
+5V
R6
C4
-12V
R1
P1
LINK PINS FOR PULSE MODE OPERATION
R5
0V
A
C1
D1
0V
20
R2
C2
R3
R4
C3
0V
B
21
LASER ON LED
R7
R8
R10
R15
LASER ON/OFF
C5
R9
+12V
C7
-12V
-12V
P1A
R14
C6
+12V
R11
R13
R12
D2
+5V
R16
LASER RESET TOGGLE SWITCH

FIG. 6

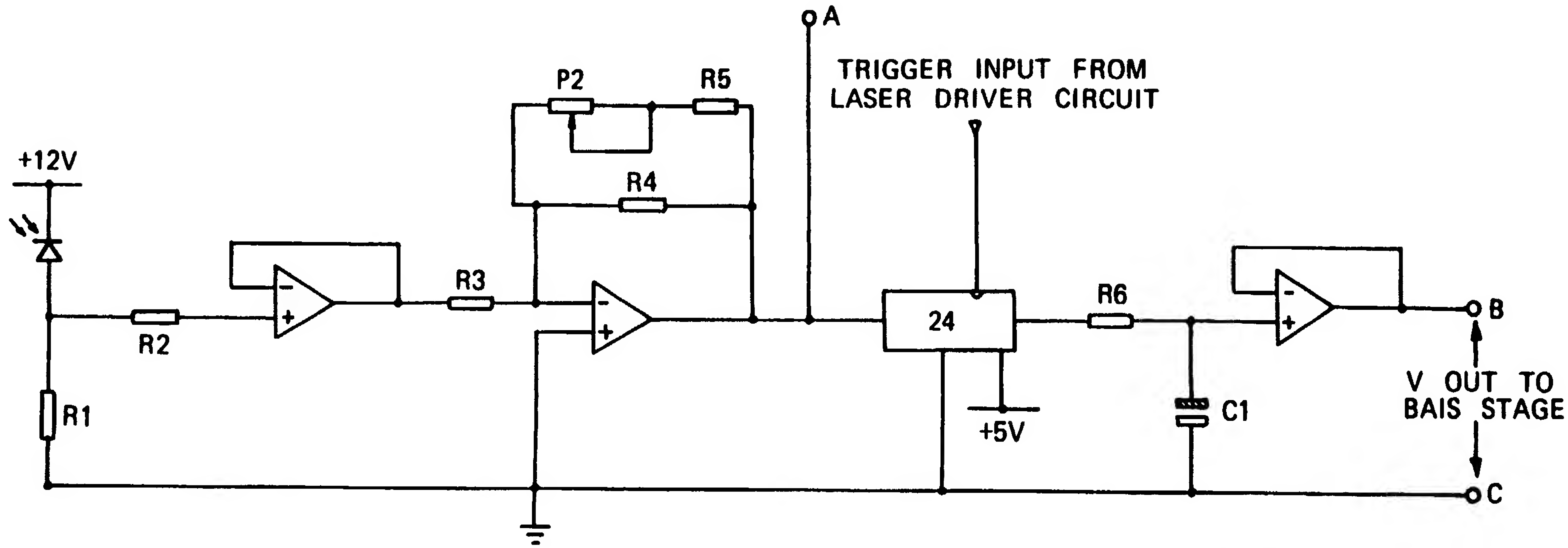
A
TRIGGER INPUT FROM
LASER DRIVER CIRCUIT
+12V
P2
R5
R4
R3
R2
R1
24
+5V
R6
C1
B
C
V OUT TO
BAIS STAGE

FIG. 7

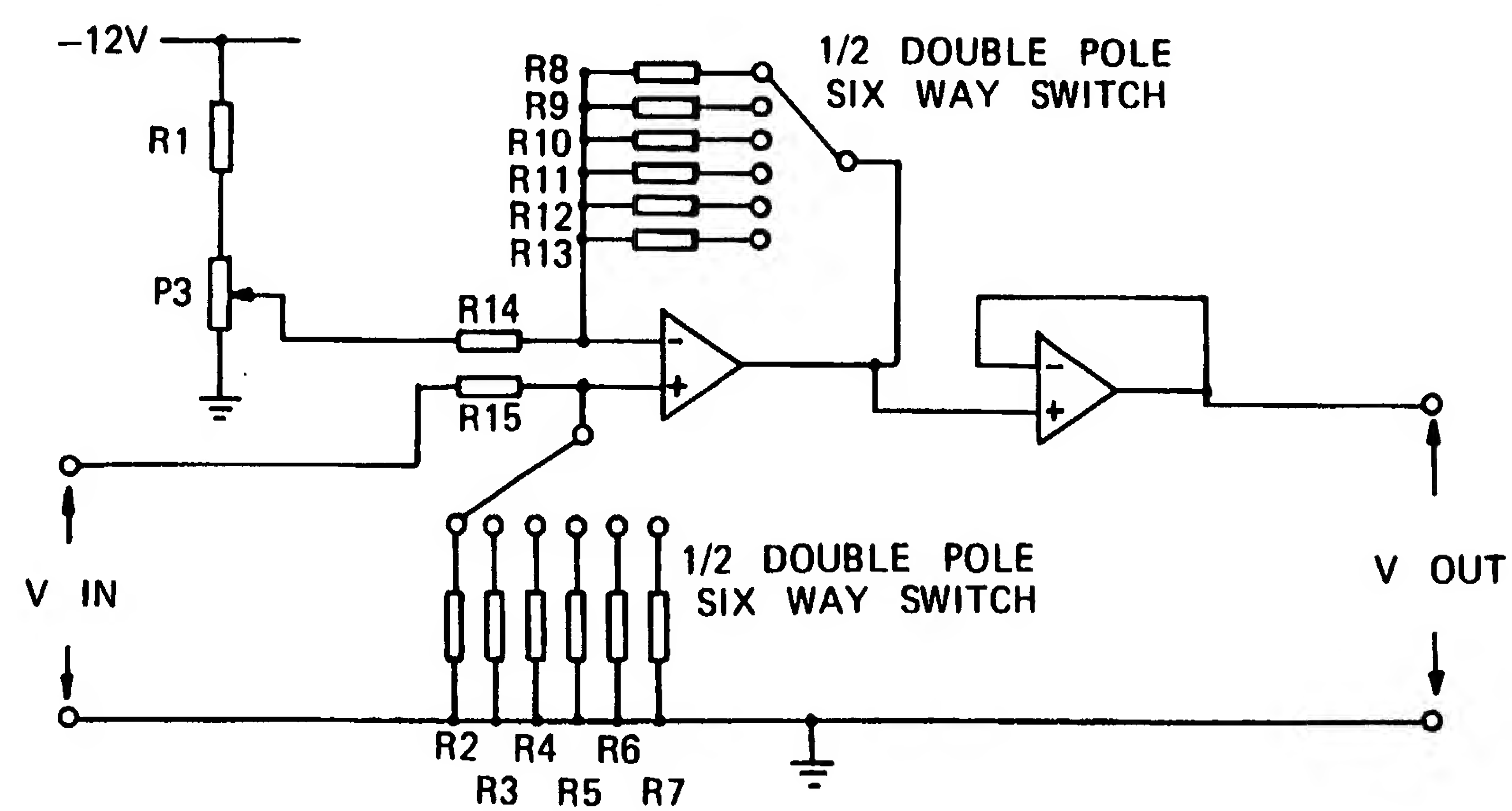
-12V
R1
P3
R8
R9
R10
R11
R12
R13
1/2 DOUBLE POLE
SIX WAY SWITCH
R14
R15
V IN
1/2 DOUBLE POLE
SIX WAY SWITCH
R2
R3
R4
R5
R6
R7
V OUT

FIG. 8

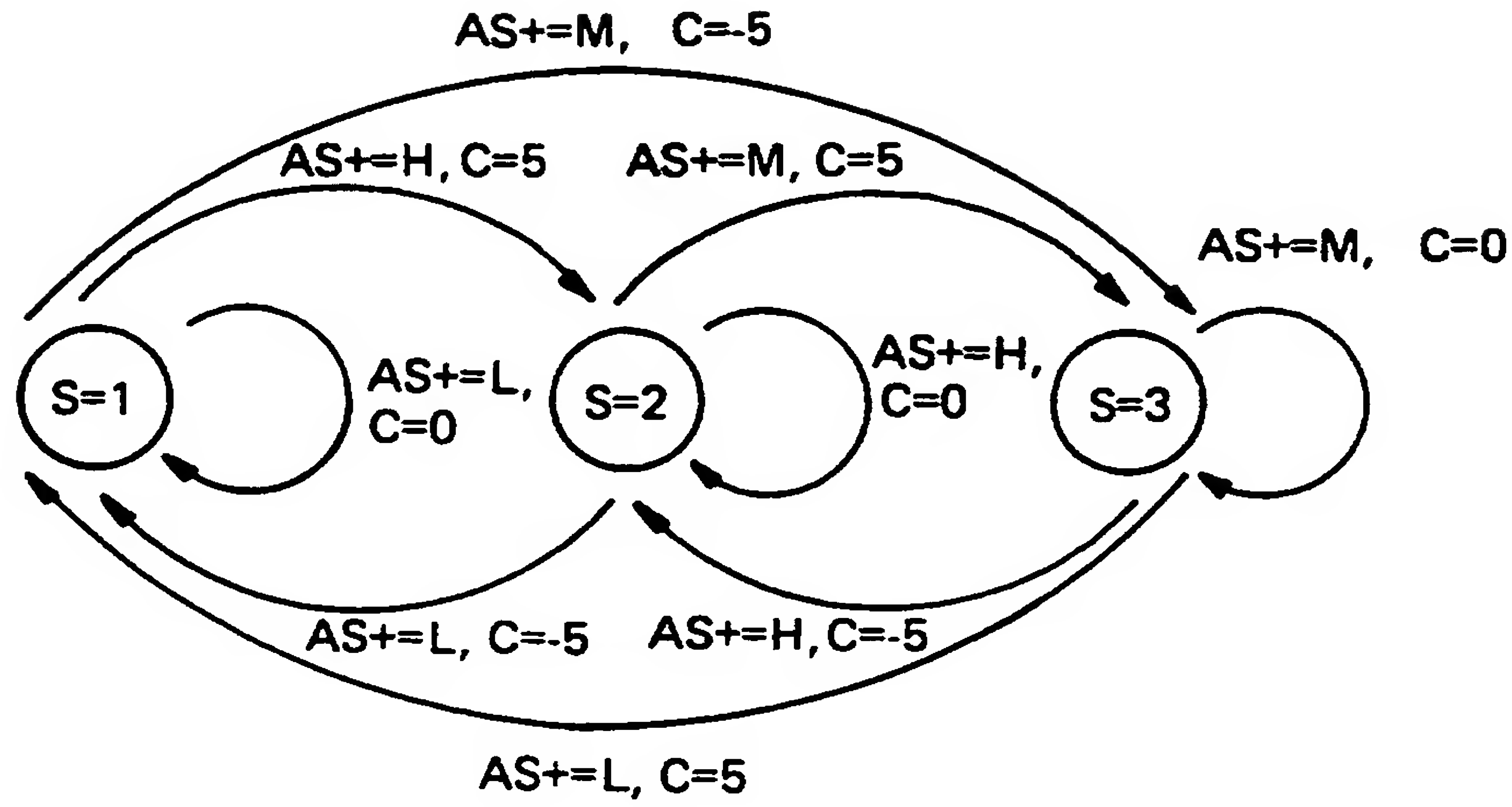
AS+=M, C=-5
AS+=H, C=5
AS+=M, C=5
AS+=M, C=0
S=1
AS+=L, C=0
S=2
AS+=H, C=0
S=3
AS+=L, C=-5
AS+=H, C=-5
AS+=L, C=5

FIG. 9

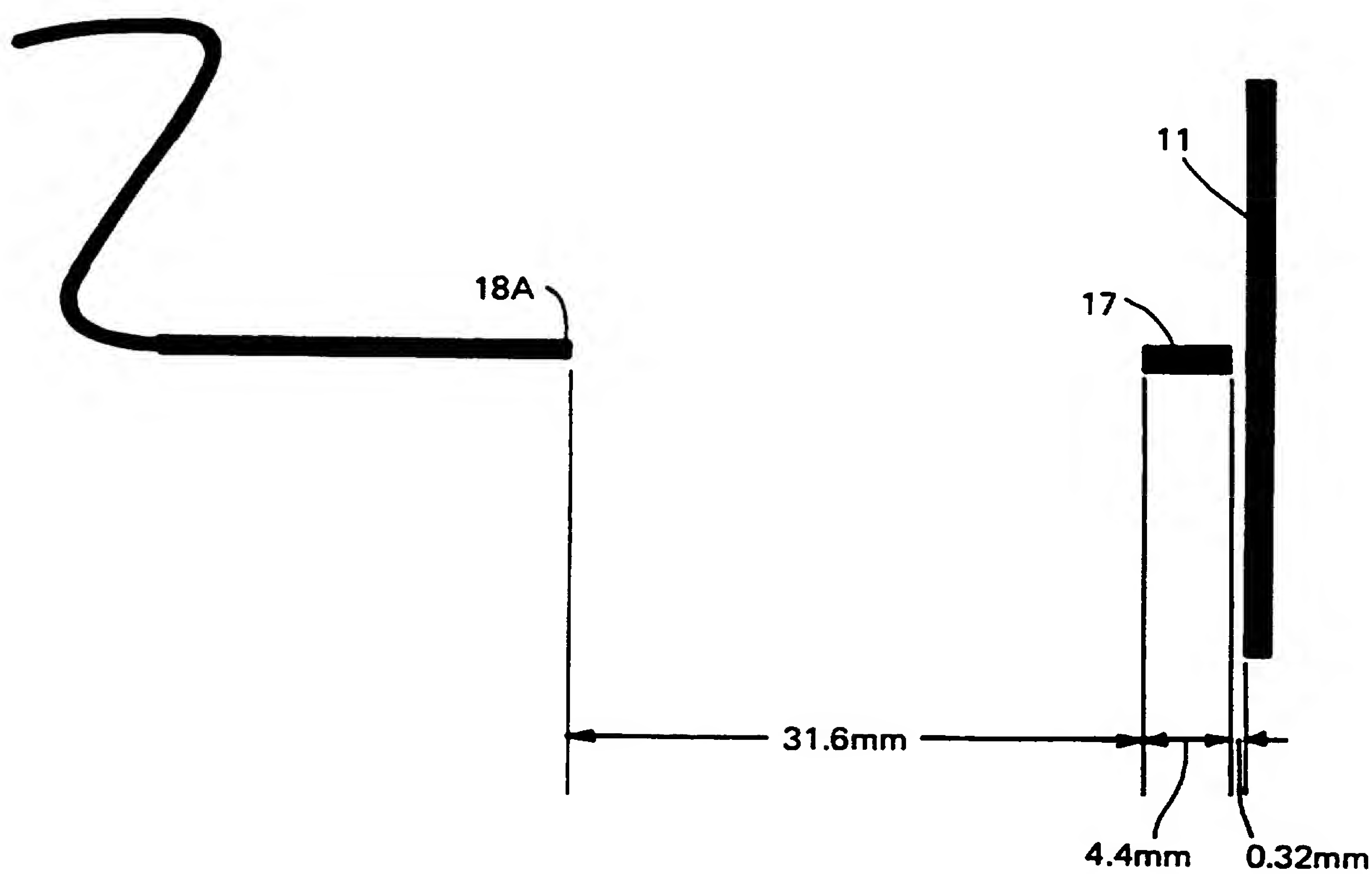
11
18A
17
31.6mm
4.4mm
0.32mm

FIG. 12

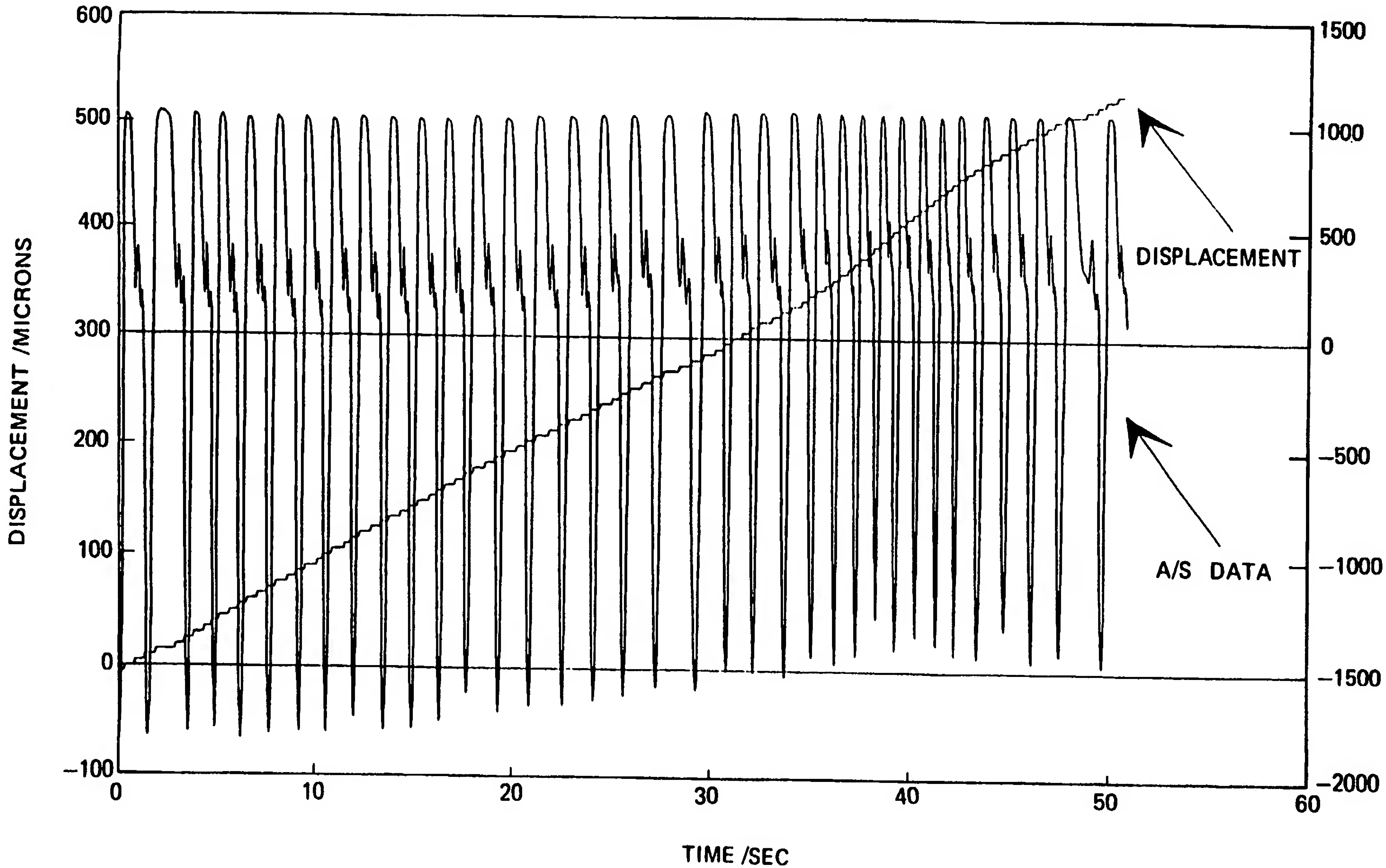
600
500
400
300
200
100
0
-100
DISPLACEMENT /MICRONS
1500
1000
500
0
-500
-1000
-1500
-2000
A/D INPUT
DISPLACEMENT
A/S DATA
0
10
20
30
40
50
60
TIME /SEC

FIG. 10

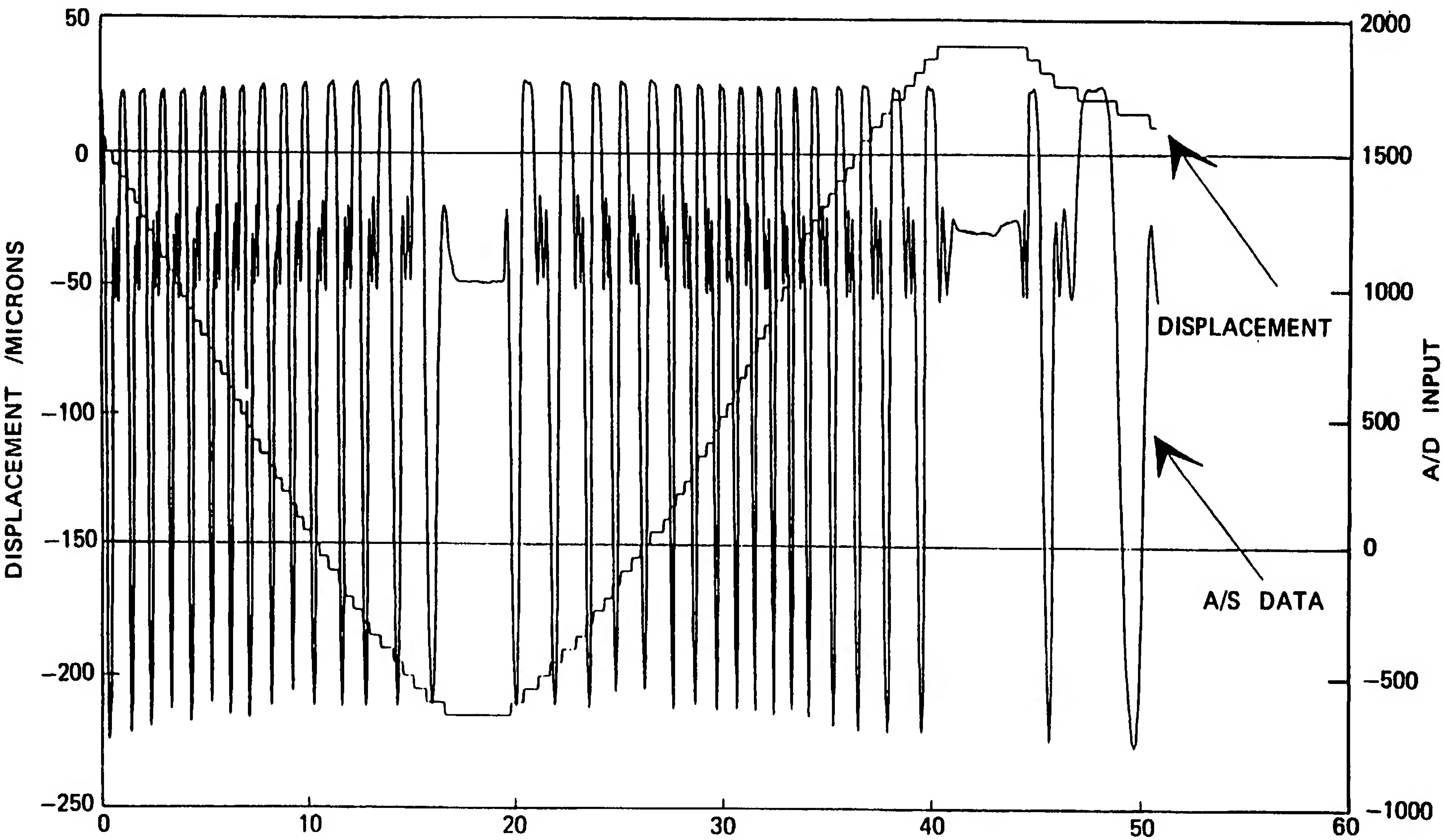
DISPLACEMENT /MICRONS
50
0
-50
-100
-150
-200
-250
A/D INPUT
2000
1500
1000
500
0
-500
-1000
0
10
20
30
40
50
60
TIME /SEC
DISPLACEMENT
A/S DATA

FIG. 11

2297840

SENSING MEANS

The invention relates to an improved device for use in sensing translational displacement. It is particularly useful for use with or adjacent to sensitive equipment.

It is known to provide an apparatus for sensing translational displacement or changes in temperature and pressure wherein a passive unit produces an optical signal representative of a differentiation in position, temperature, pressure or the like, the signal being relayed via optical fibres to a controller unit for decoding. Such apparatus, can be used with or adjacent to sensitive electrical equipment without causing interference to the equipment or other environmental noise. The controller unit can be placed remote from the passive unit in a 'safe' area so as not to cause electrical interference.

However, due to the nature of the optical signal produced, such apparatus only provides basic information about a change or displacement. It would be an advantage to have an apparatus capable of absolute position sensing while still avoiding any dangers of interference as mentioned above, i.e. an apparatus which is not susceptible to electrical noise, does not generate noise and also can be used in a hazardous area such as an explosive atmosphere.

It is, therefore, an object of the invention to produce a device for use in optical displacement sensing wherein upon illumination of part of the device, a reflected signal repres ntativ of the magnitude of a translational displacement and the direction of displacement is pr duced.

It is a further object of the invention to provid an improved apparatus for sensing translational displacement adjacent to sensitive equipment, the apparatus including a bi-directional displacement sensing device.

According to the invention in one aspect, there is provided a grating for use with an optical displacement sensing apparatus, the grating including an antisymmetric periodic pattern of reflective material, the pattern being composed of periods wherein each period has a plurality of strips of reflective material of different densities arranged in sequence, wherein part of the grating is illuminated by a concentrated beam of light, and movement of the grating reflects the concentrated beam of light to produce a code signal, the code signal being decoded by decoding means to determine the direction and extent of displacement of the grating.

Preferably there are three strips of reflective material of different densities which provide respectively three levels of reflection arranged in series, wherein the levels of reflection are defined as high, medium and low reflection.

According to the invention in a more specific aspect there is provided an apparatus for optical sensing of translational displacement, the apparatus comprising a grating having two tracks, one of the tracks including an antisymmetric (AS) periodic pattern of reflective material, the pattern being composed of periods, wherein each period has a plurality of strips of reflective material, of different densities arranged in sequence; the other track including a pseudo-random binary sequence (PRBS) pattern; a light source to provide beams of light to illuminate a part of each pattern, the beams of light being reflected off each respective track of the grating in the form of respectiv pulsed signals; means to relay the pulsed signals to a decod r; means to convert the pulsed signals to a suitable code signal for decoding, and means to decode the code signal.

By this means the optical signal is representative of the extent and direction of translational movement and absolute position sensing is achieved. The grating and light beam concentrating means may thus comprise a passive sensor unit; the light source, code signal converting means and decoding means being arranged remote from the passive sensing means forming a controller unit.

The passive sensor unit and controller unit may be connected by two optical fibres wherein both fibres relay both the source and reflected light between the units.

Conveniently the AS and PRBS tracks are provided directly beside and parallel with each other on the grating.

Preferably the light source is a laser diode. The light source may also be a light emitting diode.

Preferably the means to concentrate the beam from the light source on the tracks of the grating includes a lens arranged in front of each track.

Preferably photo diodes are arranged in the controller unit to accept the reflected optical signals from the AS and PRBS, the photo diodes being integrated with convenient electrical circuitry to produce an electrical signal for decoding.

Preferably the decoding means is a software decoder. Preferably the electrical code signal is converted to a suitable form for input to a computer for software decoding. The decoding means may also be a hardware decoder.

In ord r that th invention may be w ll und rstood it will n w b d scribed, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a plan view of an antisymmetric track of the invention;

Figure 2 is a schematic diagram of the invention;

Figure 3 is a diagrammatic side view of the passive unit of Figure 2;

Figure 4 is a diagrammatic view transverse to the view of Figure 3;

Figure 5 is an illustration of a pseudo-random binary sequences of order 3;

Figure 6 is a circuit diagram of laser diode drive circuitry;

Figure 7 is a circuit diagram of the photodetection means;

Figure 8 is a circuit diagram showing amplification means of the output signal from translational movement of both the AS and PRBS tracks;

Figure 9 represents a 'state algorithm' analysis;

Figure 10 and 11 show decoding of the algorithms; and

Figure 12 shows a specific lens/grating arrangement for one grating track.

Figure 1 shows an anti symmetric periodic track 1 for use in sensing translational displacement using sol ly optical addr ssing. The track 1 is of substantially

rectangular form having a rep ated antisymmetric pattern having periods 2 of reflective material. The pattern is preferably obtained by the deposition of chrome on glass but it could, for example, be etched onto a suitable material. Each period 2 of the track is further divided into three sections 5,6,7 of material of different reflectivities arranged in line in sequence to represent three equal levels in the reflection profile defined as low (5), medium (6), and high (7) reflectivity.

In use, part of the anti symmetric track 1 is illuminated by a light beam 8 of small diameter. This is obtained by using a lens placed at a precise distance from the track. When the track 1 is moved translationally, the light beam 8 is modulated by the changing reflection properties of the grating and is reflected back through the lens to a signal decoding means (not shown). The direction of movement of the track is determined by examination of the reflected signal which is representative of the antisymmetric reflection profile of the track. The three strips of different densities of reflective material are arranged in sequence such that a series of low 5, medium 6, high 7 reflectivity indicates movement of the track 1 in one direction and a series of the opposite order indicates movement in the other direction.

It is possible to use the antisymmetric track 1 alone in a translational displacement sensing apparatus to provide bi-directional incremental sensing. In this case it is necessary to have a reference point from which counting of the periods will determine how far the track has moved, the new position of the track, and the direction of movement.

In a specific application, (see Figures 2,3 and 4) the antisymmetric track of the invention is used as part of an apparatus for absolute sensing of translational displacement using solely optical addressing for use as a safe sensor, e.g. with or adjacent to sensitive electrical equipment. The device comprises two units: the first

unit being a passive sensing means P arranged to provide an optical signal according to the extent and direction of translational displacement (as shown by the arrows); the second unit being a controller unit A which accepts the optical signal, transforms it into an electrical code signal and arranges decoding of the electrical code signal into a numerical or graphical form. The units are connected by optical fibre cables 18 which relay both a light beam from a light source in the controller in one direction, and the optical signal produced by the passive sensor unit in the other direction.

The passive sensor unit P includes a "two track" optical grating 11 which consists of an antisymmetric periodic pattern of the type described above directly beside a pseudo-random binary sequence (PRBS) pattern. The pseudo-random binary sequence pattern is of standard type and although its properties are well known, it will now be described for reference only.

Figure 5 shows a schematic example of a pseudo-random binary sequence track 4 (of order 3) including a set of binary ones and zeros in a sequence produced by a particular mathematical algorithm. Each bit b consists of a portion of either high reflectivity material r or low reflecting material t as described above for the AS track. The sequence is **characterised by** its order 'n', which in this example is 3. The bits b are arranged so that if a window w of length 'n' bits is moved along the grating one bit at a time, the sequence of bits b in each window will be unique. This is an essential feature for absolute sensing of translational displacement.

The pseudo random binary sequence track requires a clock signal to differentiate b tween successive bits within a window. This is provided in the apparatus by the antisymmetric track since it lies parallel on the grating to the pseudo-random binary

sequence track and has a period width equal t the bit width of th pseudo-random binary sequence.

In Figures 3 and 4, the passive sensor unit P includes an optical mount 14 of aluminium which has a movable bed 15 with mechanical linkage 15A allowing translational movement of 20mm. The two-track grating 11 is attached to the movable bed 15 using index mounting gel 16.

A GRIN lens 17 is placed before each track of the two-track grating 11. The lenses 17 are arranged to concentrate respective beams of light, which are transmitted from a light source via optical fibres 18 as described below. As the grating 11 moves in the beam of light, the light concentrated on each track of the grating is reflected back through the respective lenses 17 to be relayed to the controller unit A for decoding.

The GRIN lenses 17 are situated in an aluminium block 19 which rests upon a thin rubber layer 20 placed on top of the mount 14. Nylon screws 21 are arranged one at each corner of the aluminium block 19 to extend into the mount 14. This allows the l ns-grating distance to be altered by adjusting the four corner screws 21 thus compressing or relaxing the rubber 20 by the required amount. The lens-grating distance d is a critical factor in obtaining a reflected signal with the required resolution. The lenses 17 are secured into the block using nylon screws 21A which do not obstruct any optical paths of the reflected signal.

A holder for the optical fibres 18 is constructed in aluminium around the mount 14 and allows the fibres 18 to be placed at a suitable distance from the lenses 17. Firstly, a base plate 23 is connected to the underside f the mount 14 so as not to load the rubber 20 supporting the lenses 17. Two side walls 24 are fixed to the base

plate 23 to support a top plate 25 containing the fibres 18. The fibres 18 are secured to the top plate 25 using nylon screws 26 which allow the fibre-lens distance to be adjusted. The fibre-lens distance is not such a critical factor as the lens-grating distance.

The controller unit A (Figure 2) includes two laser diodes with driver circuitry 30, to provide light beams to be transmitted to the passive sensor unit P, photodiode circuitry with amplification means 31, 3dB optical couplers 32 and a microprocessor decoding and display unit 33.

As shown in Figure 6, a feed back circuit is used to drive the laser diode 20, which may be, e.g. a Sharp LT 023 MD, and includes an integrated circuit 21 (3C01) to control the power output of the laser which is essential in achieving a stable signal suitable for decoding. Temporal changes in the laser output would give the incorrect impression of a change in reflected power from the grating and therefor the power output level must be held constant. Feedback is achieved by using a built-in photo diode within the laser package. The driver circuitry includes a soft-start facility of the on switch of the laser diode. This is required to prevent any current spikes or surges, which may damage the laser. Also, to prevent laser damage, current limiting trip circuitry is included. The cut-off current level is set by means of a pre-set resistor. The laser can be driven in either pulsed mode operation or continuous wave operation by making one connection.

The light beam from the laser diode is coupled into the 3dB fibre optic coupler 32 (within the controller) using GRIN lenses. Light passing into the coupler is split into two directions. One part travels to the passive sensor unit via the optical fibre cable, while the other part travels to a section of the optical fibre which is not used.

The light beams are focused by the lenses onto the respective track of the grating. The light is then reflected back through the respective lens along the optic fibre to the coupler, where it is again split into two directions by the coupler. One of the sections travels back to the laser diode and is not used, while the other is relayed to a photo diode, e.g. a silicon pin diode (BPX65). The amount of light that is incident upon the photo diode depends upon the section of the grating that is illuminated. The signal produced by the photo diode is an electrical signal representative of the pulsed signals relayed from the passive sensor unit, and is passed to electric circuitry to be converted to a suitable signal for input to a decoder for software decoding.

Referring to Figure 7, the circuitry used for photodetection can be seen. The photodiode signal is buffered and amplified by the first two stages of the circuitry. If the laser diode is being used in pulse mode operation, then the pulsed behaviour is removed using an analogue or digital switch 24 (DG211CJ). The signal is then filtered and buffered for output to the biassing stage from pins B and C. The output from the final buffer stage is a d.c. signal. When the laser is running C.W. output is taken from pins A and C.

As the grating moves from areas of high intensity to low intensity and vice versa, the change in the amplitude of the photodetector signal after buffering and amplification is quite small in comparison with the actual size of the signal, because of stray reflections. As it is the **change** in the photodetector amplitude with time that is of interest, not the magnitude of the amplitude itself, the output voltage from the photodetector circuitry is positively biased. This is to allow for further amplification of the signal to a convenient level for input to a comput r for position d coding. Referring to Figure 8, it can be seen that a variable gain differential amplifier is

implemented to achieve this. Finally the amplified signal is buffer d for output to a computer data acquisition board for decoding.

In Figures 6,7 and 8:

Figure 6

R1 = 1K	C1 = 0.1 uF
R2 = 100R	C2 = 0.047 uF
R3 = 100K	C3 = 100 uF
R4 = 15R	C4 = 0.33 uF
R5 = 20R	C5 = 1nF
R6 = 330R	C6 = 22 pF
R7 = 100K	C7 = 0.1 uF
R8 = 100K	
R9 = 100K	
R10 = 100K	P1 = 5K
R11 = 22K	P1A = 5K
R12 = 10K	
R13 = 10K	
R14 = 560K	
R15 = 1K2	
R16 = 1K	

Figure 7

R1 = 1M
R2 = 1K
R3 = 3K9
R4 = 20K
R5 = 4K7
R6 = 56R

C1 = 47 uF
P2 = 20K

Figure 8

R1 = 8.2K
R2 = 10K
R3 -= 30K
R4 = 100K
R5 = 300K
R6 = 510K
R7 = 1M
R8 = 10K
R9 = 30K
R10 = 100K
R11 = 300K
R12 = 510K
R13 = 1M
R14 = 10K
R15 = 10K

P3 = 20K

D coding the pulsed signal reflected from the antisymmetric track may be complicated due to the fact that each of the three levels of reflection could be assigned to a particular point. A problem may then arise if the track passes from a low state of reflection directly to a high state, wherein it briefly passes through a section which lies between the two levels. A 'state algorithm' approach (see Figure 9) may be used to avoid an incorrect level assignment. In addition to the use of two discrimination levels to decode the signals, the occurrence of reflection maxima and minima is monitored in the regions above the lower level but below the upper level to achieve correct classification. During decoding these discrimination levels are continually checked and altered. This is done to allow correct decoding of signals when the focus of the lens system changes from the optimum (i.e. walk off due to the grating position being not quite level) or the d.c bias due to temperature effects etc.

Hence, correct decoding of the antisymmetric signal can achieved even when the magnitude of the periodic variations is less than one eighth of the optimum. However, the decoding does eventually break down when the shape of the profile changes sufficiently so that certain key points such as maxima and minima within the mid region cannot be distinguished.

The key to the State Diagram of Figure 9 is as follows:

AS+	=	Next data point from AS grating. Can take one of 3 values: H - data point above the highest discriminator level L - data point below the lowest discriminator level M - neither of the above plus a local maximum or minimum has been detected.
C	=	Change in the displacement in microns.

S = State Variable

On switch-on the following states are assigned:

AS=H - S=2, AS=L - S=1, AS=M - S=3

Figure 10 and 11 show the correct working of the decoding algorithms. These show displacement against time and can be compared with the data points for the AS track.

Decoding the pseudo-random binary sequence track is quite simple as only one decision level is required identify the value of each of the bits of the sequence. The software used is capable of decoding the signals to provide a resolution of 5μm. This is achieved by dividing the period of the antisymmetric track into the three equal sections of 5μm provided by the high, medium and low reflectivity regions. Hence, the sensor provides absolute sensing with a resolution of 5μm.

An example of a specific lens 17 grating 11 arrangement is shown in Figure 12. For a desirable sensor resolution of 5μm, the design for the AS grating track has a period of 15μm and the PRBS track is of order 12 and has a bit width also of 15 μm.

As the optimum spot diameter for this grating is 3.0 μm, a lens system is needed to demagnify the spot diameter which is obtained at the end of the fibre to this size. It is advantageous to have as simple an optical arrangement as possible so a single lens system is used to achieve this. This is shown in Figure 12. Identical lensing systems are used for both the AS track and the PRBS track. It is advantageous to do this to achieve short rise (and fall) times between bit transitions of the PRBS track. The multimode optical fibre that has been used giv s a spot diameter at the fibre-end 18A of 50 μm. Therefore a magnification of -16.67 is n eded to reduce

the illuminating spot size to grating 3.0 μm. To achieve this desired magnification it has been found from GRIN theory that the lens must be position as follows:

Lens/grating distance	=	0.322 ± 0.005 mm
Lens/fibre-end distance	=	31.6 ± 0.8 mm

It can be seen that the positioning criterion of the grating with respect to the lens is much stricter than that involved in the positioning of the fibre with respect to the lens. As only one reading head is used to monitor the PRBS track, i.e. the code is being read serially, an initial minimum movement of 180 μm in one direction is require to allow absolute sensing to take place. Until this occurs, only incremental sensing can be performed by using the AS track.

CLAIMS

1. A grating for use with an optical displacement sensing apparatus, the grating including an antisymmetric periodic pattern of reflective material, the pattern being composed of periods wherein each period has a plurality of strips of reflective material of different densities arranged in sequence, wherein part of the grating is illuminated by a concentrated beam of light, and movement of the grating reflects the concentrated beam of light to produce a code signal, the code signal being decoded by decoding means to determine the direction and extent of displacement of the grating.

2. A grating according to Claim 1, in which there are three strips of reflective material of different densities which provide three levels of reflection arranged in series.

3. A grating according to Claim 2, in which the levels of reflection are of high, medium and low reflection.

4. An apparatus for optical sensing of translational displacement, the apparatus comprising a grating having two tracks, one of the tracks including an antisymmetric periodic pattern of reflective material, the pattern being composed of periods, wherein each period has a plurality of strips of reflective material, of different densities arranged in sequence; the other track including a pseudo-random binary sequence pattern; a light source to provide beams of light to illuminate a part of each pattern, the beams of light b ing reflected off each respective track of the grating in the form of

respective pulsed signals; means to relay th pulsed signals to a decod r; means to convert the pulsed signals to a suitable code signal f r decoding, and means to decode the code signal.

5. An apparatus according to Claim 4, in which the grating and a light beam concentrating means comprise a passive sensor unit and the light source, code signal converting means and decoding means being arranged remote from the passive sensing means and forming a controller unit.

6. An apparatus according to Claim 5, in which the passive sensor unit and the controller unit are connected by two optical fibres wherein both fibres relay both the source and reflected light between the units.

7. An apparatus according to Claims 4, 5 and 6, in which the antisymmetic and pseudo-random binary sequence tracks are provided directly beside and parallel with each other on the grating.

8. An apparatus according to any one of Claims 4 to 7, in which the light source is a laser diode or a light emitting diode.

9. An apparatus according to any one of Claims 4 to 8, in which the beams from the light source are concentrated on the tracks of the grating by means of a lens arranged in front of each track.

10. An apparatus according to any one of Claims 5 to 9, in which photo diodes are arranged in the controller unit to accept the reflect d optical signals from

the antisymmetic and pseudo-random binary sequence tracks, the ph to diodes being integrated with conventional electrical circuitry to produce an electrical signal for decoding.

11. A grating according to Claim 1 substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

12. An apparatus for optical sensing of translational displacement according to Claim 4 substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

FIGURE 6

R1 = 1K	C1 = 0.1 uF
R2 = 100R	C2 = 0.047 uF
R3 = 100K	C3 = 100 uF
R4 = 15R	C4 = 0.33 uF
R5 = 20R	C5 = 1nF
R6 = 330R	C6 = 22 pF
R7 = 100K	C7 = 0.1 uF
R8 = 100K	
R9 = 100K	
R10 = 100K	P1 = 5K
R11 = 22K	P1A = 5K
R12 = 10K	
R13 = 10K	
R14 = 560K	
R15 = 1K2	
R16 = 1K	

FIGURE 7

R1 = 1M	C1 = 47 uF
R2 = 1K	P2 = 20K
R3 = 3K9	
R4 = 20K	
R5 = 4K7	
R6 = 56R	

FIGURE 8

R1 = 8.2K	P3 = 20K
R2 = 10K	
R3 -= 30K	
R4 = 100K	
R5 = 300K	
R6 = 510K	
R7 = 1M	
R8 = 10K	
R9 = 30K	
R10 = 100K	
R11 = 300K	
R12 = 510K	
R13 = 1M	
R14 = 10K	
R15 = 10K	

The Patent Office

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Application No: GB 9602772.7
Claims searched: 1-4

Examiner: Gareth Griffiths
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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1A (ABAH, AEAX, ARM)

Int Cl (Ed.6): G01D 5/26, 5/32, 5/34, 5/347, 5/36

Other: Online Database: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	EP0210825 A2 (LUCAS) whole document	1, 2, 4-10

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.